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Analysis of Geomechanical Behavior for the Drift Scale Test

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1. Introduction.

The Yucca Mountain Site Characterization Project is conducting a drift scale heater test, known as the Drift Scale Test (DST), in an alcove of the Exploratory Studies Facility at Yucca Mountain, Nevada. The DST is a large-scale, long-term thermal test designed to investigate coupled thermal-mechanical-hydrological-chemical behavior in a fractured, welded tuff rock mass. The general layout of the DST is shown in Figure 1a, along with the locations of several of the boreholes being used to monitor deformation during the test. Electric heaters are being used to heat a planar region of rock that is approximately 50 m long and 27 m wide for 4 years, followed by 4 years of cooling. Both in-drift and "wing" heaters are being used to heat the rock. The heating portion of the DST was started in December, 1997, and the target drift wall temperature of 200°C was reached in summer 2000.

A drift-scale distinct element model (DSDE) is being used to analyze the geomechanical response of the rock mass forming the DST. The distinct element method was chosen to permit explicit modeling of fracture deformations. Shear deformations and normal mode opening of fractures are expected to increase fracture permeability and thereby alter thermal-hydrologic behavior in the DST. This paper will describe the DSDE model and present preliminary results, including comparison of simulated and observed deformations, at selected locations within the test.

2. Work Description

A DSDE model of the DST has been formulated to simulate the thermomechanical response of the rock mass. This model uses the 3DEC code (Itasca, 1998) and provides for explicit modeling of fracture deformation. The thermal field input to the simulation is derived directly from thermal measurements made during the test. Figures 1b and 1c show, respectively, the drift geometry and associated fracture planes used in the simulations. The fracture locations and orientations were determined by analysis of borehole video logs. Time dependent deformation, observed during the test to date using

Multi-Point Borehole Extensometers (MPBX), has been used to inform our simulations and "calibrate" the model. The magnitude and spatial distribution of normal and shear fracture deformation is described and used to aid in interpretation of hydrological observations. Simulations have also been conducted using a continuum representation of the rock mass.

3. Results

3.1 Simulation of Mine-by.

Prior to the excavation of the Heated Drift (HD) three boreholes were drilled from the Access and Observation Drift (AOD) perpendicular to the planned location of the Heated Drift. These boreholes were instrumented with MPBX systems and deformation was recorded during the excavation of the Heated Drift. Simulation of the borehole response due the excavation shows that at ambient temperature, the bulk and shear moduli of the rock are 16 and 10 GPa, respectively.

3.2 Simulation of MPBX measurements during heating phase.

The DSDE model has been used to simulate the MPBX measurements made in several boreholes. The 3DEC code was used to simulate the rock mass as both a discontinuum and a continuum. For the discontinuum simulation, the system of fractures and blocks shown in Figure 1c was simulated. For the continuum simulation, the fractures shown in Figure 1c were removed, and the rock mass was simulated as a large, elastic block. The same temperature field was used for each simulation, and temperatures at each calculation time were derived from a 3 dimensional temperature field developed by interpolation of the temperatures measured in the test at that time.

Results indicate that for about half of the MPBX boreholes, the continuum and discontinuum formulations fit the observations equally well. These results indicate that a coefficient of thermal expansion of 4×10^{-6} /°C is appropriate for this rock mass. This is consistent with values determined for the Single Heater Test, also conducted at Yucca Mountain (CRWMS M&O, 1999). Results also show that, for several of the boreholes drilled into the roof of the HD, the discontinuum predictions match the observations more closely than do the continuum simulations. An example is shown in Figure 2, which shows observed and predicted behavior for Borehole 156. This borehole is collared in the crown of the Heated Drift and extends vertically upward (see Figure 1a). Figure 2 shows that both models underpredict the early deformation, but that the discontinuum model shows excellent agreement with observations after 450 days of heating, while the continuum model continues to underpredict the deformation. The increased deformation is attributed to slip along a fracture in the discontinuum model.

3.3 Predicted Fracture deformations.

3DEC provides information on the normal and shear fracture displacements. Predicted normal mode fracture deformations are concentrated along and above the Heated Drift (Figure 3a). The results indicate similar magnitudes and spatial distributions of normal deformations at all four times. Some normal mode opening is indicated after 4 years of heating on two subvertical fractures that extend to the edge of the modeled region. This fracture opening is not shown after 8 years, indicating that normal mode opening may be reversible.

Predicted shear fracture deformations shown in Figure 3b are also concentrated above the Heated Drift, but are generally larger, and the predictions for 4 and 8 years are very similar, indicating that the shear deformation may not be recoverable upon cooling. The predicted fracture deformations are consistent with observed microseismic and acoustic emission activity, which indicate that rock movement is occurring along a few vertical fractures above the Heated Drift.

4. Conclusions

We have simulated the Drift Scale Test at Yucca Mountain using discontinuum and continuum approaches. Results provide guidance on values of the rock mass mechanical properties and on the nature and location of deformations in the test. Discontinuum simulations match the observed behavior somewhat better than the continuum simulations.

5. References.

CRWMS M&O 1999, *Single Heater Test Final Report.* BAB000000-01717-5700-00005 REV 00 ICN 1. Las Vegas, Nevada: CRWMS M&O ACC: MOL.20000103.0634.

Itasca Consulting Group, Inc. 1998. 3DEC Three Dimensional Distinct Element Code User's Guide, Version 2.00. Minneapolis, MN: Itasca Consulting Group, Inc.

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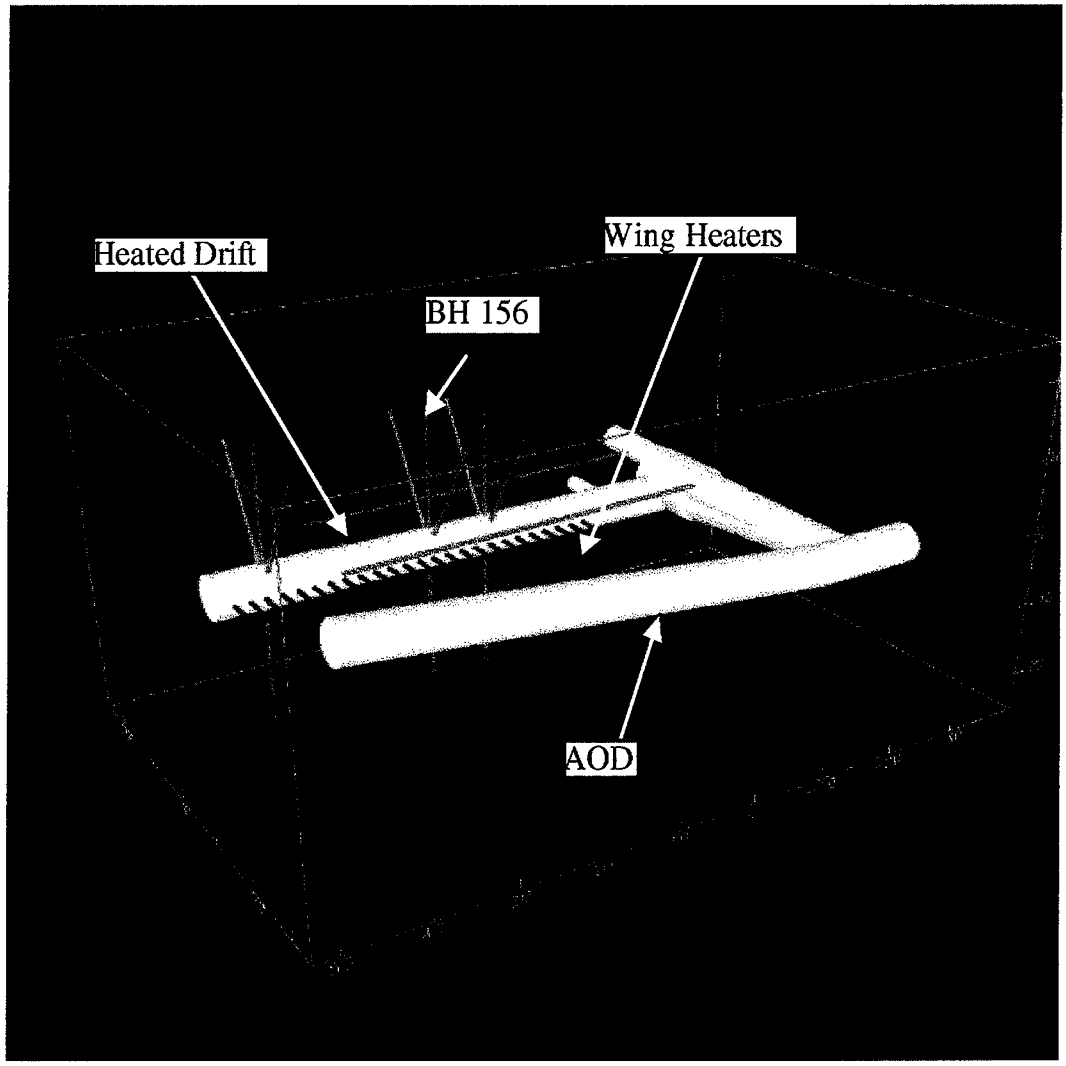
Heated Drift
Wing Heaters
BH 156
AOD

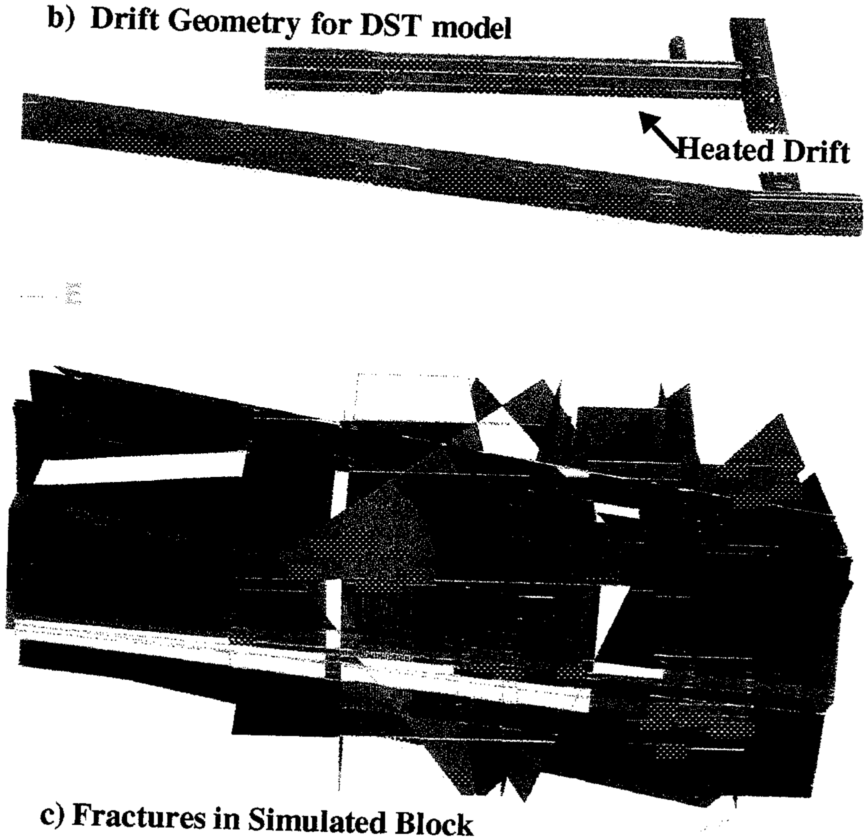

Figure 1. (b) Drift geometry for Drift Scale Test simulation. (c) Fracture geometry within simulated block. Note that the drifts shown in (b) are contained within the rock mass shown in (c).

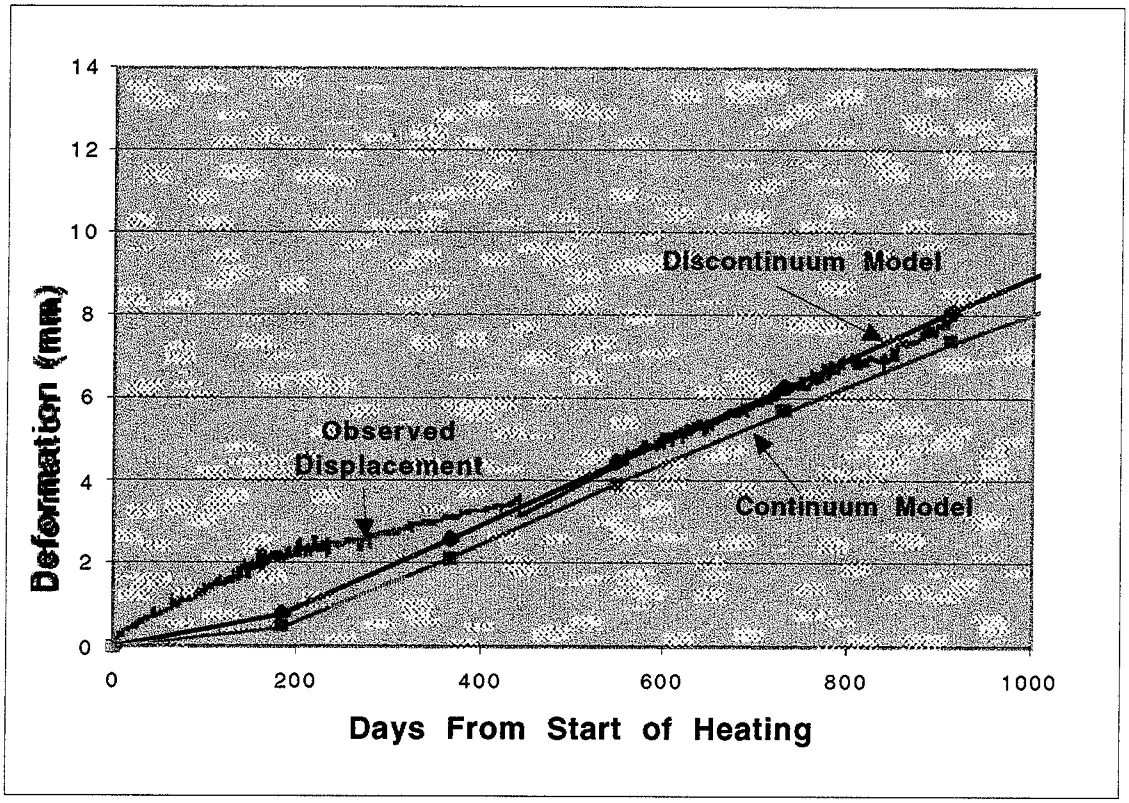

Figure 2. Comparison of observed and predicted deformation for Borehole 156 in the DST.

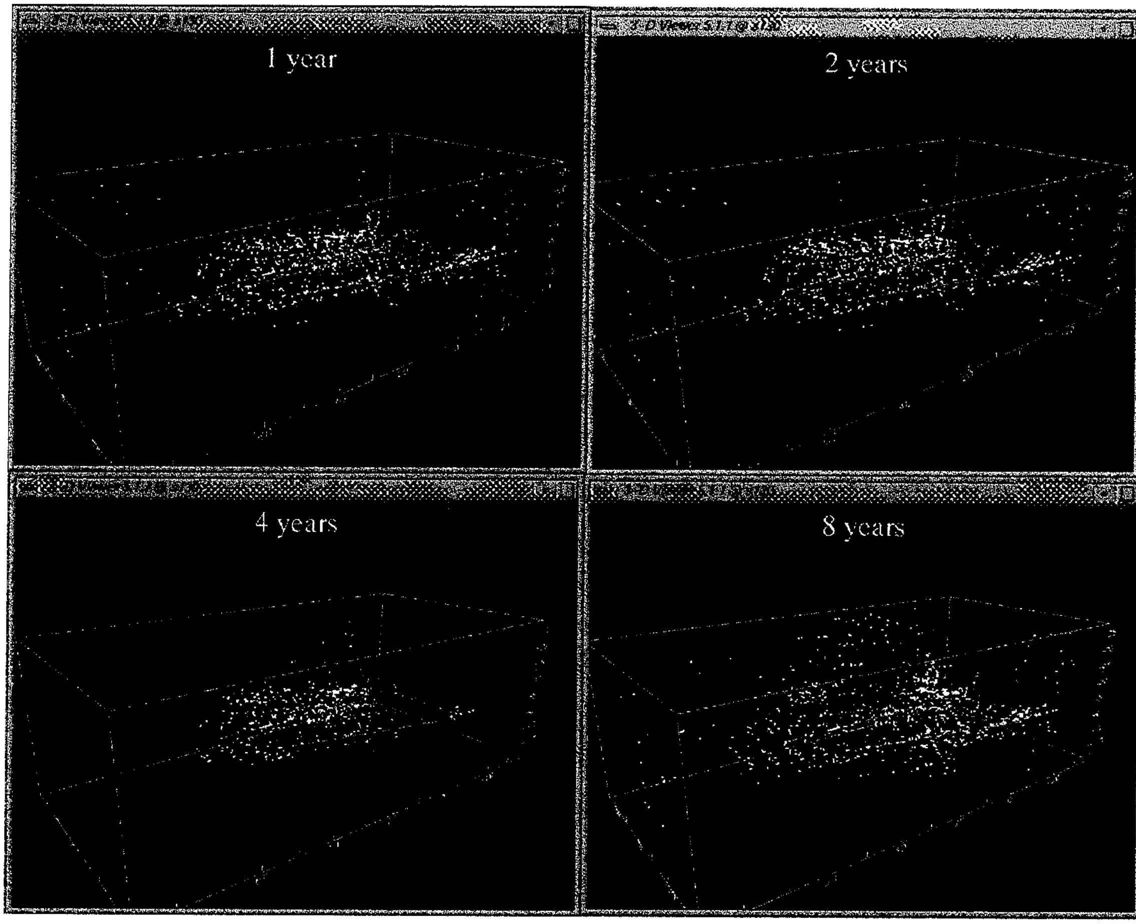

Figure 3a. Perspective view of the DST region showing predicted normal mode fracture displacements (colored dots) after 1, 2 and 4 years of heating, and at 8 years, following four years of cooling. Legend is given in Table 1. Faint white lines indicate centerlines of drifts.

Color	Fracture Deformation (mm)
White	< -0.5 (normal closing)
Light Purple	-0.05 - 0.0 (normal closing)
Dark Purple	0.0 – 0.1
Blue	0.1 – 0.5
Green	0.5 – 1
Yellow	1 - 2
Red	>2

Table 1. Legend for fracture displacement plots. Negative values pertain only to normal mode deformations.

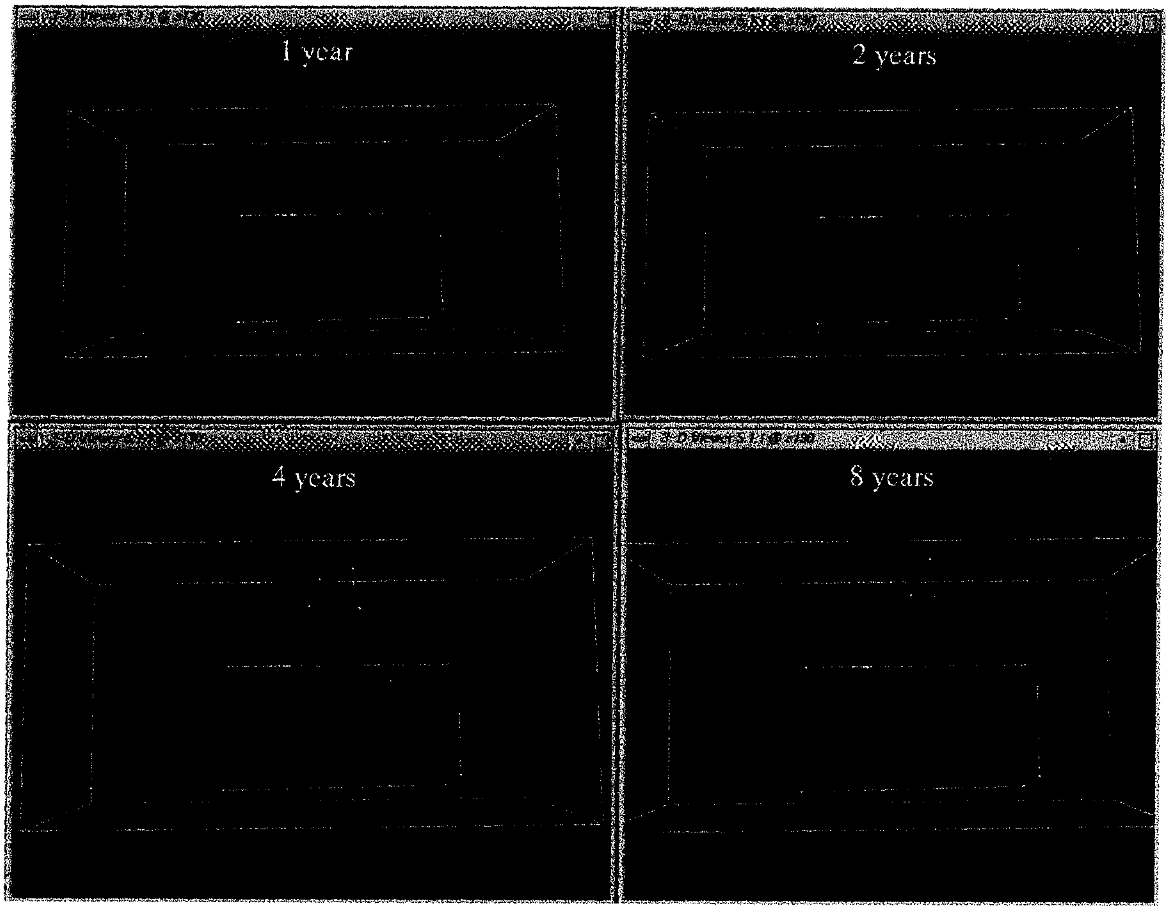

Figure 3b. Top view of the DST region showing predicted shear fracture displacements (colored dots) at the same times as Figure 3a. Legend is given in Table 1. Faint white lines indicate centerlines of drifts.

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